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Constant Level Lighting

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The Effect of a Constant Level Lighting Control System on Small Offices With Windows

by
Lee Edgar

To reduce energy consumption stemming from lighting, some of the fixtures in Army office buildings have been delamped and building energy managers have instituted the policy of turning lights off when not in use. Even with these measures, lighting is still one of the largest consumers of electricity. The current problem is to find ways to reduce the energy consumption of lighting systems when they are in use.

The objective of this research was to provide information on the performance and energy savings potential of constant level lighting (CLL) controls. Based on a review of product information, researchers selected the Conservolite Plus 20 for testing and installed it in 10 office spaces. After 4 months of operation, a survey of the office occupants revealed they were satisfied with the CLL system.

Although electrical cost savings were realized, the payback period varied greatly, depending on the cost of replacing old or inoperable lamps and ballasts.

Before large scale installation of CLL systems, it is recommended that the power factor and harmonic distortion be monitored at a large facility.

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The objective of this research was to provide information on the performance and energy savings potential of constant level lighting (CLL) controls. Based on a review of product information, researchers selected the Conservolite Plus 20 for testing and installed it in 10 office spaces. After 4 months of operation, a survey of the office occupants revealed that they were satisfied with the CLL system.

Although electrical cost savings were realized, the payback period varied greatly, depending on the cost of replacing old or inoperable lamps and ballasts.

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FOREWORD

This work was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC), under Reimbursable Order E87900273 dated 19 July 1990, "Constant Level Lighting." Willam Ell, CEHSC-FUM, was the technical monitor.

The work was performed by the Energy and Utilities Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. David M. Joncich is Chief, ES. The technical editor was Gloria J. Wienke, USACERL Information Management Office.

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LTC E.J. Grabert, Jr. is Acting Commander of USACERL, and Dr. L.R. Shaffer is Director.

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THE EFFECT OF A CONSTANT LEVEL LIGHTING CONTROL SYSTEM ON SMALL OFFICES WITH WINDOWS

1 INTRODUCTION

Background

Lighting is one of the largest consumers of electricity in Army office buildings.[1] Building energy monitors are aware of this and have instituted the policy of turning off lights when not in use. Some of the lamps in fixtures in noncritical areas (such as hallways) have been removed to save energy. Even with these measures, lighting is still one of the largest consumers of electricity. The current problem is to find ways to reduce the energy consumption of lighting systems when they are in use. The U.S. Army Construction Engineering Research Laboratory (USACERL) was tasked with evaluating constant level lighting (CLL) systems, which may be a solution to the problem for Army offices with windows.

Many government offices have windows. Light from the window is usually available during normal working hours. Unfortunately, the overhead electrical lighting systems are designed for the worst case—when there is no sunlight available. Most of the overhead lighting systems were designed and installed when excess lighting levels and energy consumption issues were not a concern. Many work spaces are overlit, by today's standards, even before the light available from the window is added.

A solution to this problem is to control the output of overhead lights. Many overlit offices have delamped some fixtures to reduce electrical consumption. The offices can only be delamped to the point the overhead lights still provide acceptable lighting levels when sunlight is not available. When sunlight is available from the windows, electrical energy is wasted overlighting the work space.

Excess overhead lighting can also increase heat in a building. Reducing the lighting load will reduce the amount of cooling required to offset the heat generated. The reduced cooling load would be most noticeable on multilevel buildings in warmer climates. Glare is common in overlit spaces and can actually reduce employee effectiveness by causing headaches and eye strain.

Constant level lighting systems can provide energy savings by controlling the overhead lights to alter their output in response to the available sunlight. When available sunlight increases, the CLL controller dims the overhead lights to keep the light level constant in the space.

For this report, constant level lighting control systems are defined as systems that try to maintain the light level on the work surface at a constant or near constant level. The light switch on the wall could be considered a simple example if the occupant uses it to turn off the lights when sufficient sunlight is available. Using this definition, CLL systems include both simple time clock and dimmer combinations and more complex systems using controllers with light sensors that measure the light level in the space. The ultimate goal of the CLL system is to maintain a constant light level on the work surface. The system would require a light sensor, a means to control the overhead lights, and also a means to control the

[1] Stephen J. Treado and John W. Bean, *The Interaction of Lighting, Heating and Cooling Systems in Buildings - Interim Report* (U.S. Department of Commerce, National Institute of Standards and Technology, September 1988), p 1.

amount of light coming through the window. A window shading device would be necessary for instances where the sunlight coming through the windows overlights the space with the overhead lights turned off.

Objective

The objective of this research was to provide information on the performance and energy savings potential of constant level lighting controls in an office environment.

Approach

Researchers reviewed the product literature for CLL systems and selected a system for testing. The system was installed in offices at USACERL to determine any installation problems. Office occupants were surveyed to determine what effects, if any, the system had on the performance of their duties. The system was monitored in several offices to determine energy savings and any other notable properties, and the final step was to perform a bench test to verify field measurements.

Scope

This report documents the findings for only the Conservolite Plus 20 constant level lighting system tested for 4 months in 10 offices. Long term reliability is not addressed in this report.

Mode of Technology Transfer

It is recommended that this information be included as a supplement to Technical Note (TN) 81-4, *Conserving Electrical Energy.*

2 TEST SYSTEM SELECTION

Market Evaluation

CLL systems are divided into two categories based on the type of controller used. One controller works with special dimming ballasts; the other controller works with standard magnetic ballasts. Variations on these two types are provided by different inputs to the controller and by the controller sophistication. The controllers can have inputs for a light sensor, a motion detector, or a timer. More sophisticated controllers will accept multiple inputs and may contain various programmable features.

The controller that uses special dimming ballasts acts as the interface between the ballasts and the sensor inputs. The ballasts dim according to the output signal from the controller, which adjusts its output signal based on input from the sensors. A typical CLL system using dimming ballasts is shown in Figure 1. The wire from the controller to the dimming ballast carries a low voltage signal.

The controller used with standard magnetic ballasts adjusts the amount of power available to the ballasts and lamps. The controller ties into the power supply line (120 or 277 volts alternating current [VAC]) ahead of the ballasts. A typical CLL system using standard magnetic ballasts is shown in Figure 2. When the controller dims the lights, it reduces the amount of power available to the lighting system. The controller used with standard ballasts uses the same type of inputs as the controller used with dimming ballasts.

One type of CLL system uses a timer as the input to the controller. The controller dims the overhead lights at preset times following a preset light level output curve. A wide range of sophistication is available for timer-controller CLL systems.

A simple timer system only dims the lights at one time, then restores them to full brightness at another time. Figure 3 shows the typical system layout for a simple timer CLL system and Figure 4 shows the lighting system output versus time. This type of system saves the same amount of energy every day of use. The system does not compensate for weather or seasonal changes, so the work space still may be overlit or underlit.

A more sophisticated timer system would dim the overhead lights each minute following a preset curve to compensate for the average available window sunlight. For example, this system would begin ramping the overhead light intensity down at 9 a.m. until it reached minimum intensity at 12:30 p.m. The system would then begin ramping the system back up until about 6 p.m. when it would be back at full intensity. Figure 5 shows the light level output versus time for an advanced timer CLL system. A system like this could also compensate for the change in the length of the daylight hours during the year but does not compensate for cloudy days, so the space occasionally may be underlit. The energy savings for this type of system is constant from year to year.

CLL systems using a light sensor actually measure the light level in the space and adjust the overhead lights to compensate for the light coming in the windows. The light sensor gives a low voltage signal based on the amount of light in the room. The controller uses this signal to determine if the light in the room is above or below the desired preset level. The controller then adjusts the lights until the preset value is achieved. The amount of energy saved by this system depends on the amount of sunlight available to the space and the condition of the lamps and luminaries, and will vary from day to day and season to season. Weather will also cause variations in the sunlight available and therefore the energy saved.

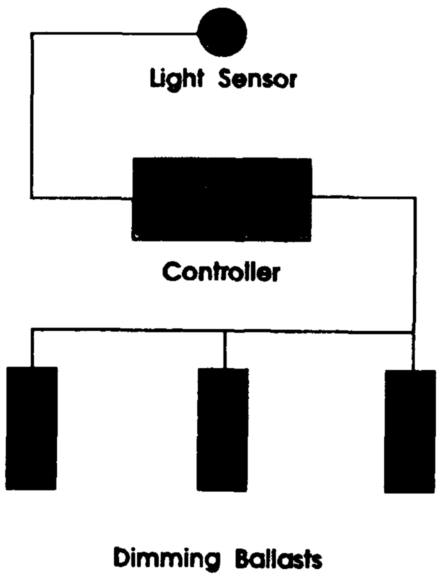


Figure 1. A typical CLL system with dimming ballasts.

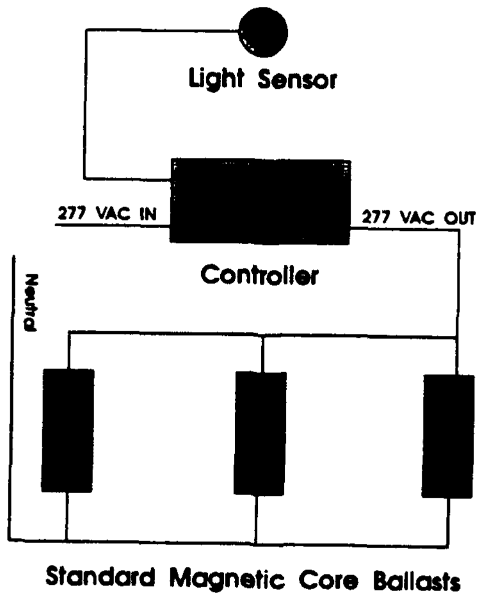


Figure 2. A typical CLL system with magnetic ballasts.

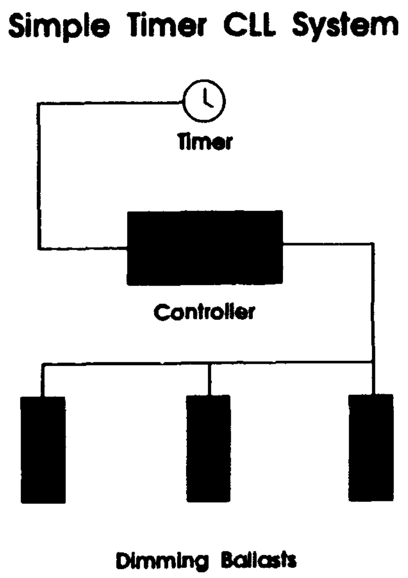


Figure 3. A simple timer CLL system.

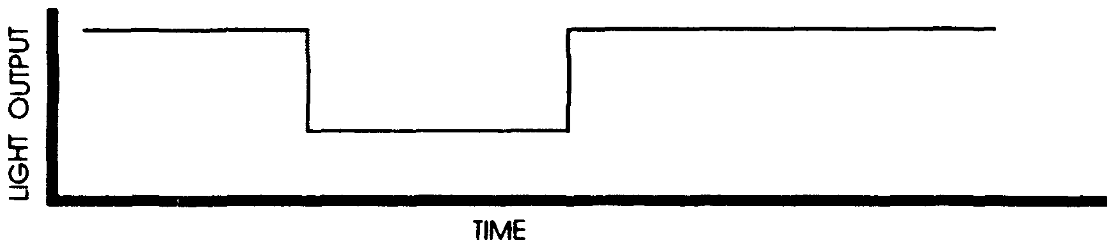


Figure 4. Timed CLL system output versus time.

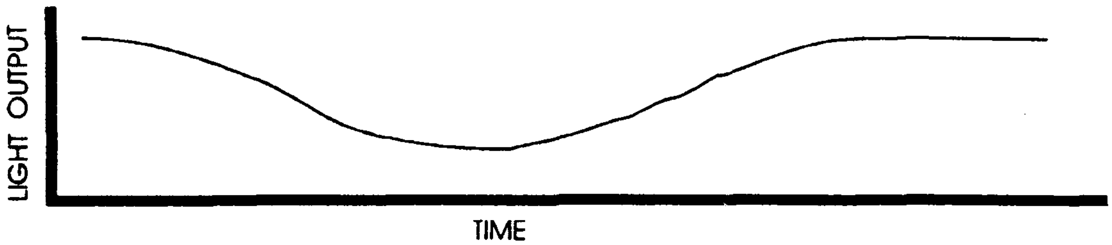


Figure 5. Light output versus time for an advanced timed CLL system.

Other variations of CLL systems add a motion detector or occupancy sensor. The occupancy sensor can be used to shut the lights off completely if no one is in the space or to turn up the lights in dimly lit space as someone enters.

The first variation would typically be used in an office (Figure 6). When the office is occupied, the lighting is held at the preset level. If the office is vacated, the entire lighting system is shut off. The second variation might be used if low level lighting was necessary for security, but full lighting was necessary only if someone entered the space (Figure 7). The energy savings for these systems vary with the occupancy patterns and sunlight available to the space.

System Criteria

Researchers wanted to test a flexible system; one that would work as well in a large meeting room as in a small office. The control network could not be large and the system could not require a large number of lighting fixtures to show an effective return on investment (ROI). The system also had to use standard ballasts, which have a cost advantage by eliminating the need to retrofit the fixtures with dimming ballasts.

Final Selection

Ten lighting control manufacturers (Appendix A) responded to a request for product information in the form of either product literature or product specification sheets. Not all of the manufacturers listed produce CLL systems. Researchers reviewed this information and selected the Conservolite Plus 20 for testing. It is described in detail in Chapter 3.

Site Selection

To reduce lead time, researchers selected USACERL as the field site for evaluating the CLL systems. The Facilities Support Branch installed the systems. Offices with west, south, and north facing windows were selected. One office with south facing windows had an occupancy sensor already installed in the lighting system. This sensor was incorporated into the CLL system so the combination could be tested.

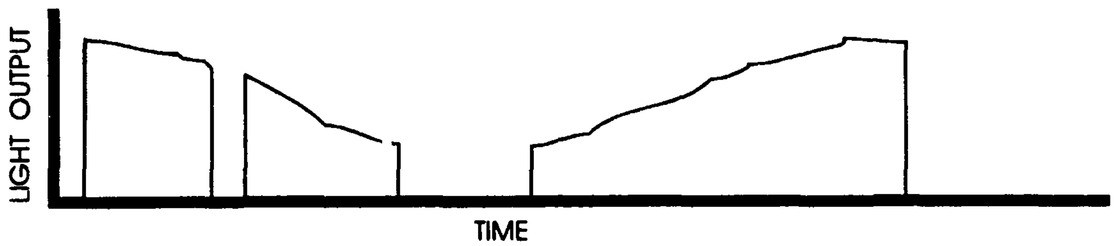


Figure 6. Light output versus time for an office system.

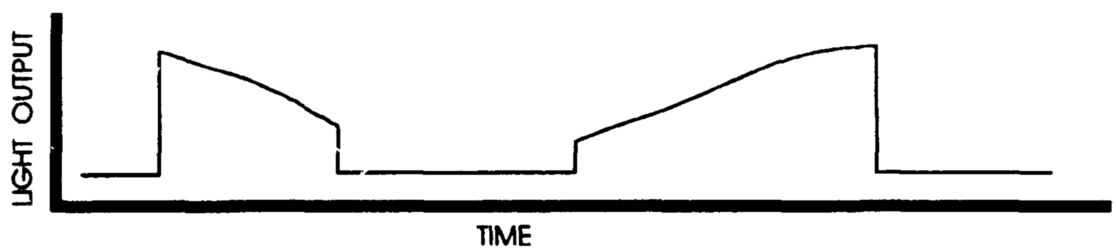


Figure 7. Light output versus time for a security system.

Researchers decided that USACERL would be one of the toughest field applications of the CLL technology since most of the offices had been delamped to conserve energy. The light level in many of the offices had been reduced to the minimum acceptable for the case of no available sunlight. The opportunity exists for energy savings using the CLL technology because the offices are overlit when the sun is shining.

USACERL also provided a proving ground where the people using the equipment were technically oriented and could provide valuable information on the product performance. These people watched the lighting system with a critical eye and would quickly spot deficiencies.

3 THE CONSERVOLITE CONSTANT LEVEL LIGHTING SYSTEM

System Description

The product selected for testing is the Conservolite Plus 20. It contains standard magnetic core ballasts and incorporates the light sensor with the controller (Figure 8). The controller is about the size of a ballast and mounts inside the light fixture. The light sensor is connected to the controller by a fiber optic cable. The light sensor mounts to a tile of a suspended ceiling.

The light sensor consists of a faceted clear plastic stem threaded into a plastic holder (Figure 9). The plastic holder connects the stem to the fiber optic cable. The desired light level is adjusted by screwing the plastic stem into the holder. The controller will dim the lights as the stem is screwed into the holder and brighten as the stem is unscrewed. The faceted end of the stem collects room light and directs it into the fiber optic cable. When the stem is screwed all the way in the holder, the end threaded inside the holder is almost touching the end of the fiber optic cable. Nearly all the light collected by the stem is transmitted to the cable. As the stem is unscrewed from the holder, the distance between the stem and fiber optic cable is increased. This larger gap results in some of the light collected by the stem end being absorbed by the holder. This manual adjustment is capable of setting the light output to any point in the range from full bright to full dim. Since the light sensor measures the total light level in the room, the controller powers up the lamps to compensate for dirt on the luminaries and lens. This increases the amount of energy required to light the space and reduces the savings. This should give users incentive to keep the luminaries clean to maximize savings.

The Conservolite system is designed to work with standard F-40, 40-watt lamps. The gas used to fill standard 34-watt, energy saving tubes causes them to flicker as they are dimmed. The F-40 tubes dim without noticeable flicker. USACERL had retrofitted most fixtures with 34-watt tubes as an energy saving measure. The 34-watt tubes were replaced with new F-40 tubes when the CLL system was installed in the light fixture.

The Conservolite Plus 20 controllers are designed to compensate for the increased bulb wattage by dimming the fixture to 80 percent of full output 10 seconds after the lamps strike. This 80 percent of full output is now the brightest the fixture will get even if there is no sunlight available. The Conservolite Plus 20 controllers will dim to a minimum 30 percent of full output.

The Conservolite Plus 20 control units come in sizes that allow the control unit to dim standard fixtures with two, four, six, or eight lamps. The Plus 20 can control ballasts in multiple fixtures, as long as the number of ballasts controlled is the correct number for the unit. Figure 10 shows the wiring diagrams for all four modules and their ballast connections.

System Installation

The system was installed in 10 different offices of the Energy and Utilities Systems Division (ES) in the center building of the USACERL complex. Seven offices have south facing windows, three have west facing windows. One of the offices with south facing windows had an occupancy sensor. The sensor was left in place ahead of the Conservolite controller.

Nine of the offices are single occupant 9 ft by 12 ft* spaces with a single 3 ft by 8 ft window. The other two offices are 18 ft by 12 ft spaces with two occupants. Each of these two offices has two 3 ft by 8 ft windows. All the windows are fitted with either horizontal or vertical blinds. Figure 11 shows the basic layout of the two types of offices and the placement of the windows.

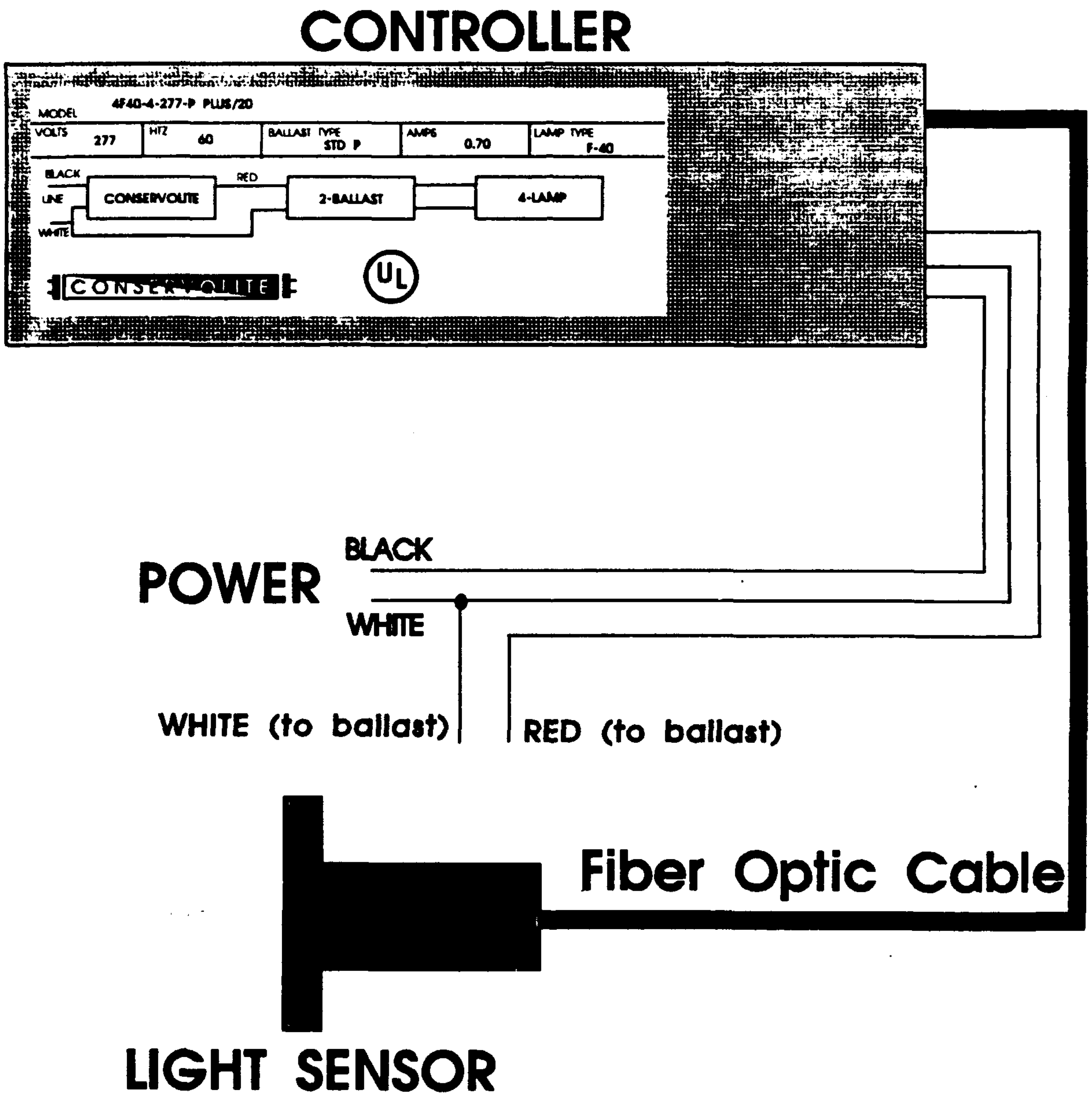


Figure 8. The Conservolite system.

* A metric conversion table is provided on page 27.

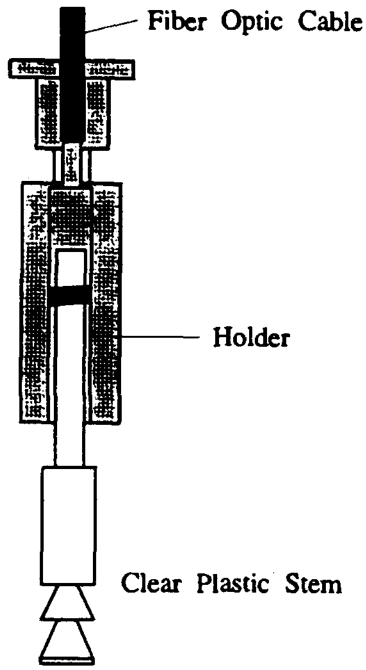


Figure 9. The system's light sensor.

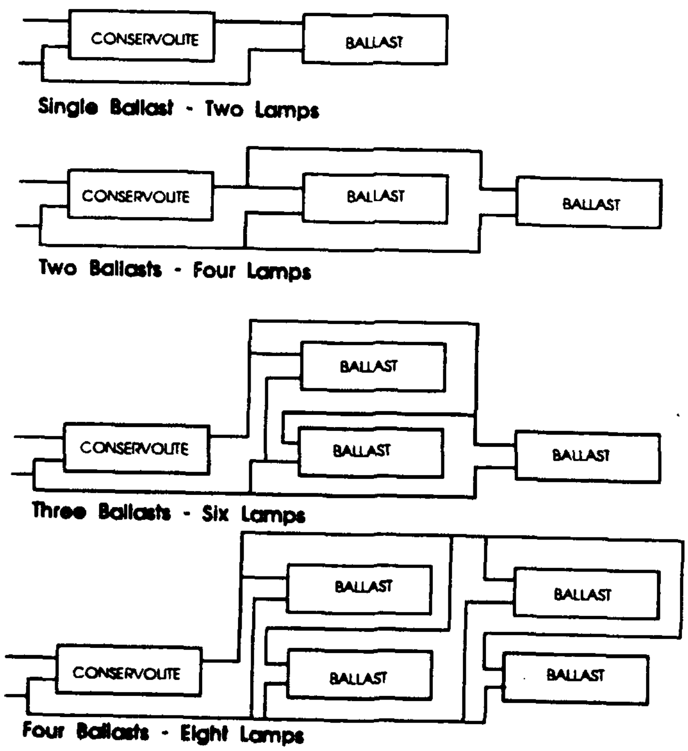


Figure 10. Conservolite wiring diagrams.

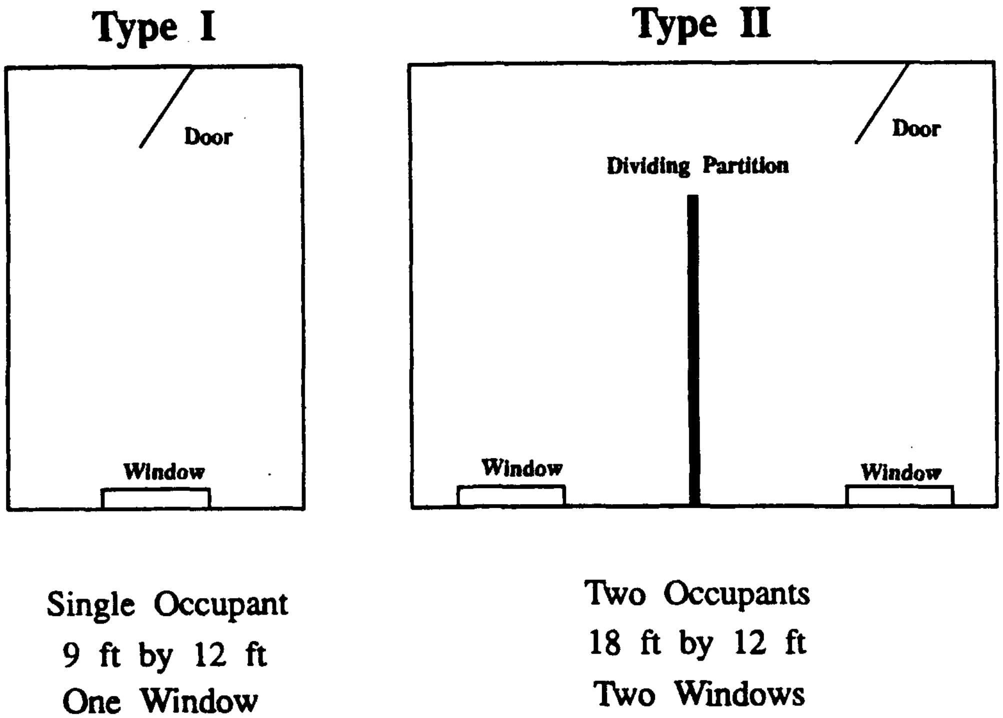


Figure 11. Layout of test offices.

The Conservolite controllers were installed in offices with the original ballasts to see if the units would work with the old ballasts. Unfortunately, problems developed with the system right after installation. When the controller first strikes the lamps, it powers them at 100 percent and dims to 80 percent of full bright after 10 seconds. This would normally be a smooth ramping down, but in several of the offices the lights would flicker so intensely that it resembled a strobe light.

After checking the wiring for correct installation, a telephone call to Conservolite confirmed the opinion that the ballasts needed to be replaced. The representative said that for retrofit applications, the ballasts would have to be replaced in order for the system to operate correctly. New class P magnetic core ballasts were installed and the flicker ceased.

The ballasts found in most offices dated back to the early 1970's. One office, a recent addition to an open bay area, is still using the original ballasts, which are approximately 10 years old. The lights in that office flicker slightly as the lamps are initially ramped down. These ballasts also produced a hum after the system was installed.

One office (room 273) had a marginally bad ballast in the circuit, which caused one fixture to dim much more than the others. This fixture did not brighten and dim with the other fixtures; it remained dim. The controllers are current-sensitive and when they detect an overcurrent, they switch the lights to full bright and disconnect themselves from the circuit. The marginal ballast was not pulling enough current to cause the controller to switch out of the circuit, but a surge in the lighting circuit would cause the lights to go full bright. At one point, turning off the lights in an adjacent office would cause a surge sufficient to cause the lights to go full bright. Replacing the bad ballast resolved the problem.

Two of the offices were wired to a Synergistic Controls Systems, Inc. C-180 data acquisition system so the power factor, kilowatts, current, and voltage level could be recorded. The system was mounted in a closet between two offices. A donut current transformer (CT) was placed around the hot leg of the feed to the lighting circuit in each office. A potential transformer (PT) was attached to the 277 VAC that feeds the lighting circuits. The solar radiation was recorded manually every hour during the workday with a Dodge Products Solar Meter Model 776.

User Survey

After the system had been operating for 3 months, the occupants were surveyed to find out how well they thought it operated. The survey questions and responses for questions 3 through 9 are shown in Table 1. One occupant did not return the survey.

Respondents said the CLL system did not affect their work effort. Seven respondents indicated initial flickering when the lights were turned on. This is characteristic of the Conservolite system. The intensity of this initial flickering varied slightly from office to office. Three users said they had sudden shifts in the light level. The cause was bad ballasts in the lighting system. These ballasts were replaced and the systems now operate normally.

Most of the users responded that they did not have any noise from the CLL system. One user responded that there was noise, but it was not noticeable when the computer was on. The respondents were divided on the issue of glare reduction. The amount of glare on the work surface depends on how it is positioned relative to the light fixtures and to the window.

The CLL system did not affect the window shade use of most of the occupants. Opening the shades would reduce the light output of the CLL system and would increase the energy savings.

Several users responded that their system exhibited abnormal characteristics. One system (in room 273) experienced dimming due to a malfunctioning ballast. The other users were referring to shifts in the light level. In most instances, replacing a bad ballast resolved the problem. In one office, a controller had to be replaced before the system operated correctly.

Field Testing

Offices 274 and 274-A were monitored for 1 month to determine the lighting system power demand versus time and solar radiation. The offices were also monitored for the power factor and line voltage.

The top graph in Figure 12 shows the electrical demand of the lighting system in room 274 for a sunny day (January 15, 1991). The horizontal line on the graph is the power consumed by the original lighting system with the 34-watt lamps. The data were recorded from 8:07 a.m. until 6:08 p.m. The sudden drops in the data are due to the occupancy sensor turning the lights off when the room was unoccupied. The lower graph shows the solar radiation versus time for the same day and time period.

The graphs in Figure 12 show the reduced lighting power with increases in available sunlight. The lights reached full dim by 8:40 a.m. (33 minutes after the test began) when the solar radiation reached 50 Btuh/sq ft. The light reached full bright near 3:30 p.m. The system increased light output to near full bright when the solar radiation dropped below 10 Btuh/sq ft. The system remained at full dim as long as the outdoor solar radiation remained above 40 Btuh/sq ft. At full dim, the system only used 50 percent of the power consumed by the original lighting system.

Table 1

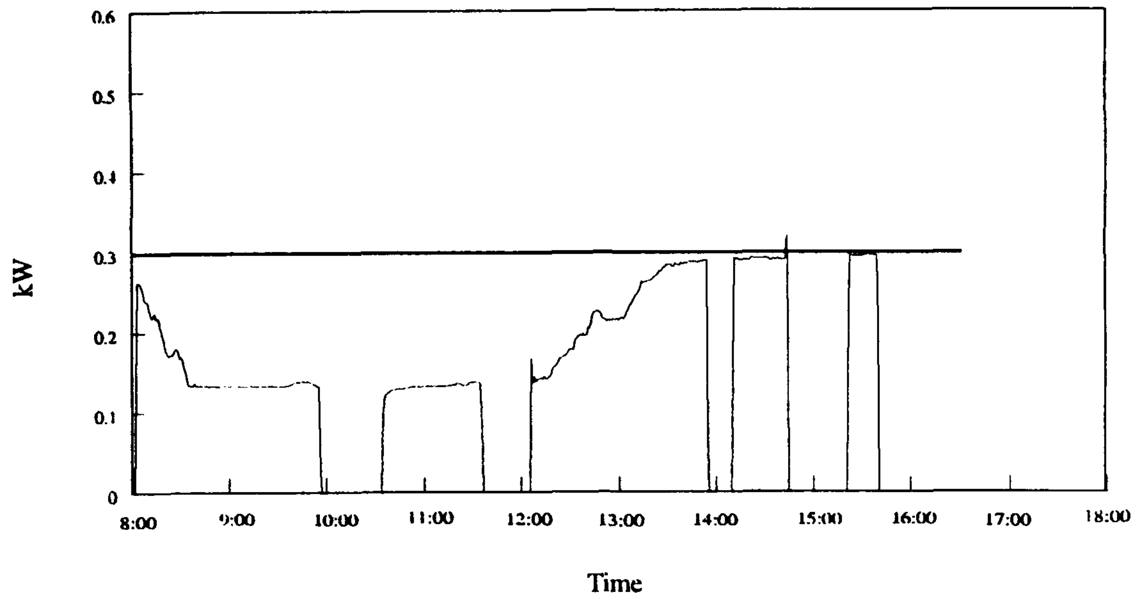
Survey Questions and Responses

Question	Yes	No	No Response
1. Name ____________			
2. Office room number ____________			
3. Did the constant level lighting system affect your ability to perform work in your office?	0	9	1
4. Did you have "flickering" when first switched on?	7	3	0
5. Did you have sudden shifts in light level?	3	7	0
6. Did you have any noise with the system?	1	9	0
7. Do you feel the system reduced glare?	4	5	1
8. Did the system affect your window shade usage?	1	9	0
9. Did the CLL system demonstrate any abnormal characteristics? If yes, please list them.	4	6	0
10. Any other comments on the constant level lighting system?			

Figure 13 shows how the system responded on a cloudy day. The lower graph shows that the solar radiation did not climb above 20 Btuh/sq ft. The power versus time graph shows that the power was reduced only 10 percent below the original system. This was during the period of maximum dimming.

Figure 14 shows the power versus time for the lighting system in room 274-A. The upper graph contains data for January 28, 1991, which was a sunny day. The lower graph contains data for January 16, 1991, which was a cloudy day. Unlike room 274, there is very little difference in the power profiles for the sunny day versus the cloudy day. The variation in the power on the sunny day is less than 100 watts. The horizontal line on both graphs shows the power used by the original lighting system. The new CLL system uses 35 to 40 percent less power than the original system.

The lack of variation in the profile for the sunny day appears strange until several things are taken into account. Room 274-A has 6 fixtures with 4 lamps each. Four of these fixtures are over nonwork or noncritical areas and are dimmed as much as possible with the manual adjustment. The other two fixtures are over work surfaces and are adjusted so the light output approaches full bright on cloudy days or at dusk. One of these fixtures and its light sensor are placed between the two windows where they do not get direct sunlight. This prevented the fixture from dimming as much as the fixture directly in front of the window.



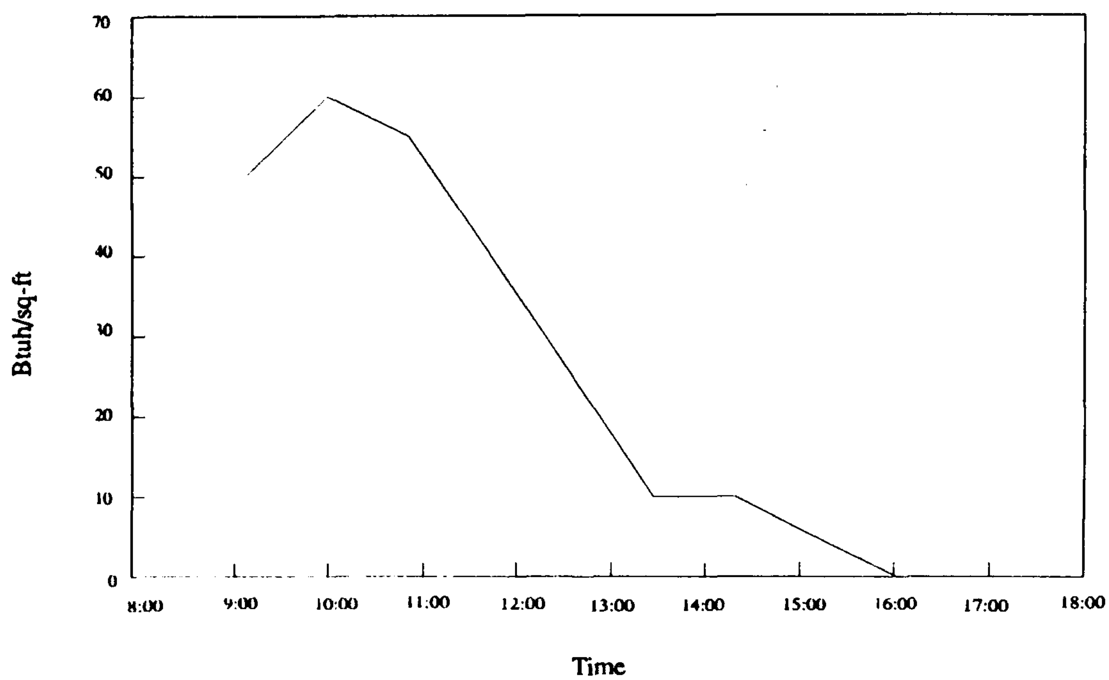
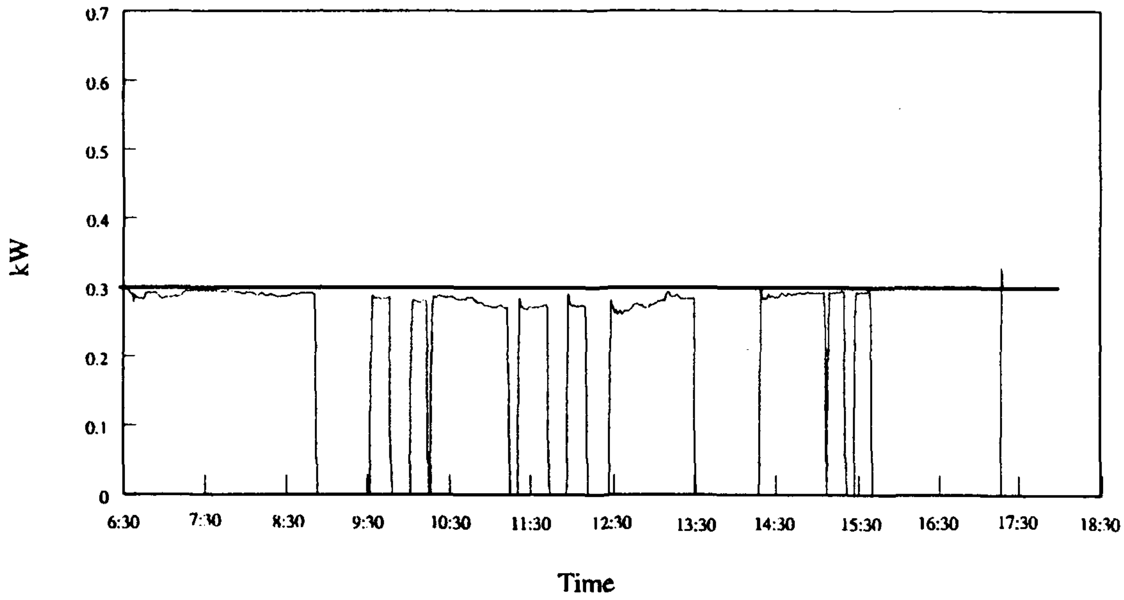


Figure 12. Electrical demand and solar radiation for a sunny day.



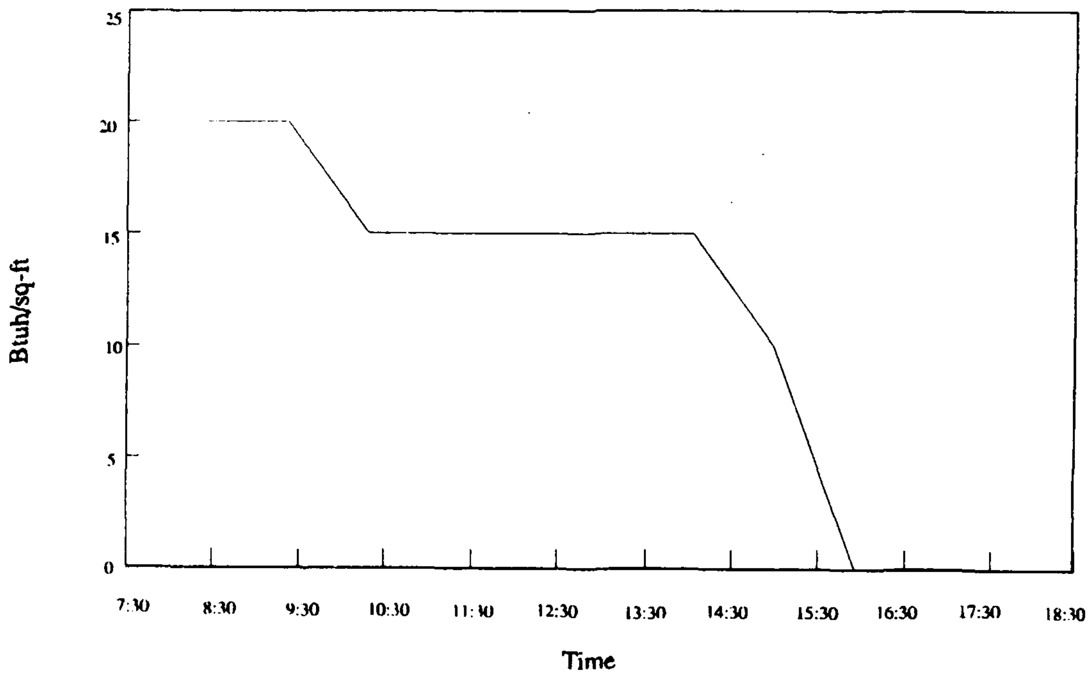
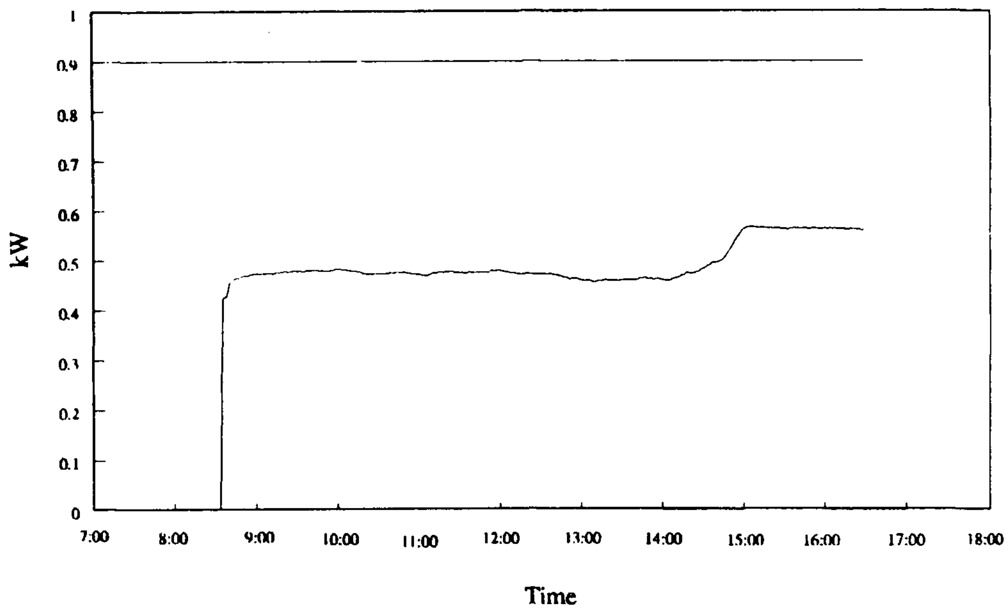


Figure 13. Electrical demand and solar radiation for a cloudy day.



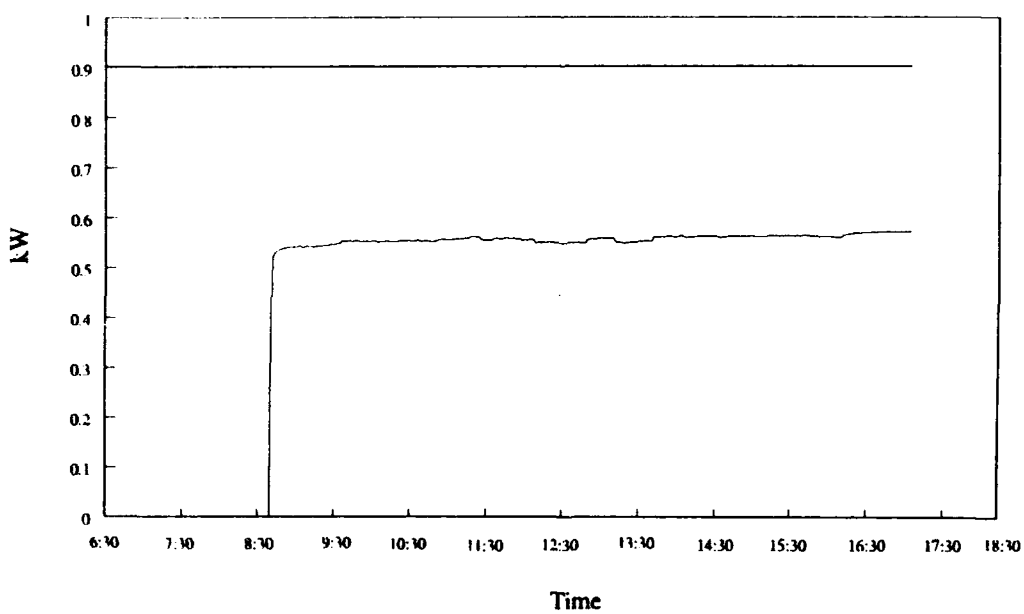


Figure 14. Power versus time for a sunny and a cloudy day.

A more cost-effective retrofit would be to use a combination of delamping and CLL controls. The fixtures over the noncritical areas could have been delamped from four tubes to two. The two fixtures over critical areas would still be fitted with the CLL controllers. The problem with delamping arises in the changing mission and use of an office. Every time the use of the space changes, the lamps have to be reinstalled and ballasts reconnected. The CLL controllers allow the user to adjust the light level of each fixture to meet the new mission.

Power Factor

Researchers recorded the power factor in offices 274 and 274-A during the monitoring period. Figure 15 contains graphs of the power factor versus time on January 28, 1991. The top graph is for room 274; the bottom graph is for room 274-A. The top graph for room 274 shows the power factor ranging from 0.6 to 0.7 during periods when the lights are on and the system is operating. The bottom graph shows the power factor ranging from 0.68 to about 0.75 when the system is operating.

This low power factor for the Conservolite CLL system could cause the user to be charged a power factor penalty if the system is installed extensively in a building. Many larger buildings are metered for the power factor; building owners are charged a penalty if the power factor falls below a certain level, which is usually in the range of 0.9 to 0.95. USACERL is charged for a 0.88 power factor and pays a small penalty. This penalty amounts to less than 1 percent of the total bill. Using the month of January 1991 as an example: if the power factor dropped to 0.70, the total bill would have increased 4.6 percent. At 0.70 power factor, the penalty would account for 5.1 percent of the total bill.

Originally, USACERL was contracted to maintain a .90 or better power factor and paid a penalty if it dropped below this level. Now, USACERL is penalized for poor power factor by a monthly peak KVAR charge. As the power factor drops below 1.0 the KVAR peak increases dramatically.

Another office at USACERL (room 272), which did not have the CLL system, was checked for the power factor. The lighting system in room 272 has a mix of old and new ballasts and uses 34-watt tubes in all the fixtures. The power factor was measured using a Dranetz Series 901 Power Analyzer. The power factor measured for the lighting system was 0.76 and would be typical for most offices at USACERL with older components in the lighting system. Lighting systems with new ballasts and lamps exceed the 0.95 power factor level.

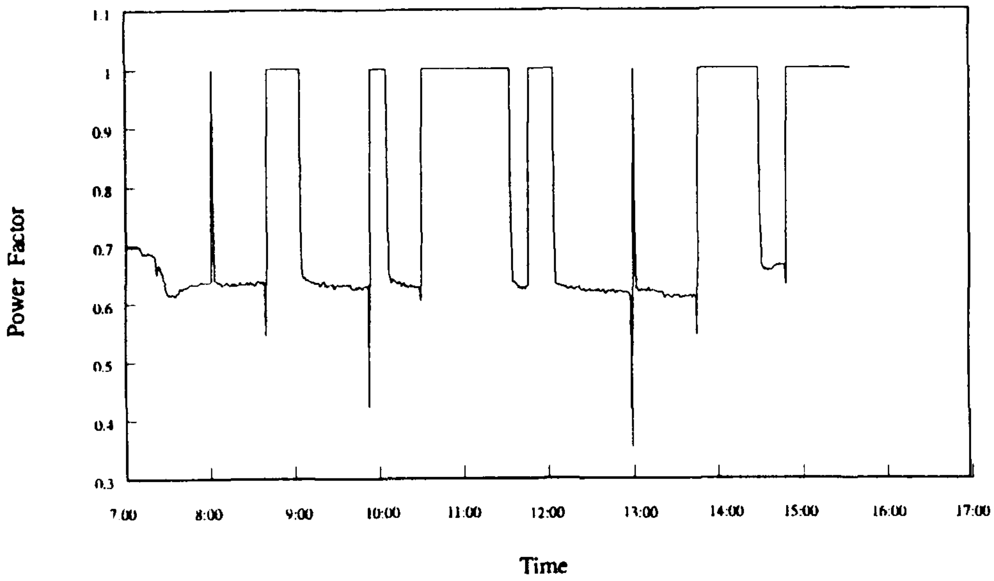
Researchers performed a bench test to determine the effect of the Conservolite CLL controller on the power factor for a single ballast and two F-40 tubes. This test is discussed below in **Laboratory Testing**.

Harmonics

The CLL system installed in room 274-A was tested to determine if it is a source of significant harmonics. Harmonics in a building can cause serious problems and as the amount of electronics in a building increases, the level of harmonics also increases. These problems range from computer failures to overheating in transformers and motors.[2]

The lighting system in room 272 was tested to determine the harmonic level of a system with the old ballasts and 34-watt tubes. The harmonic content due to lighting in offices 272 and 274-A was measured using a Dranetz 901 Power Analyzer. The harmonic content of room 272 is compared to room 274-A, which has the CLL system installed, in Figure 16. The bar graph shows the current magnitude for the harmonic orders 2 through 25.

[2] "Hands-on Approach to Solving Harmonic Problems, Part 1," *The Power Monitor*, Vol 1, No. 3, December 1990.



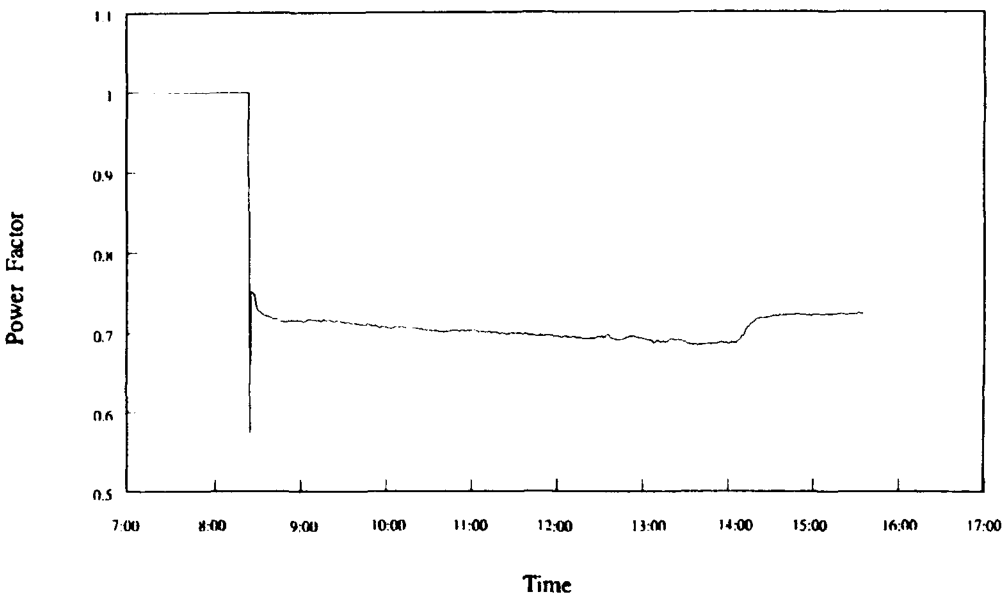
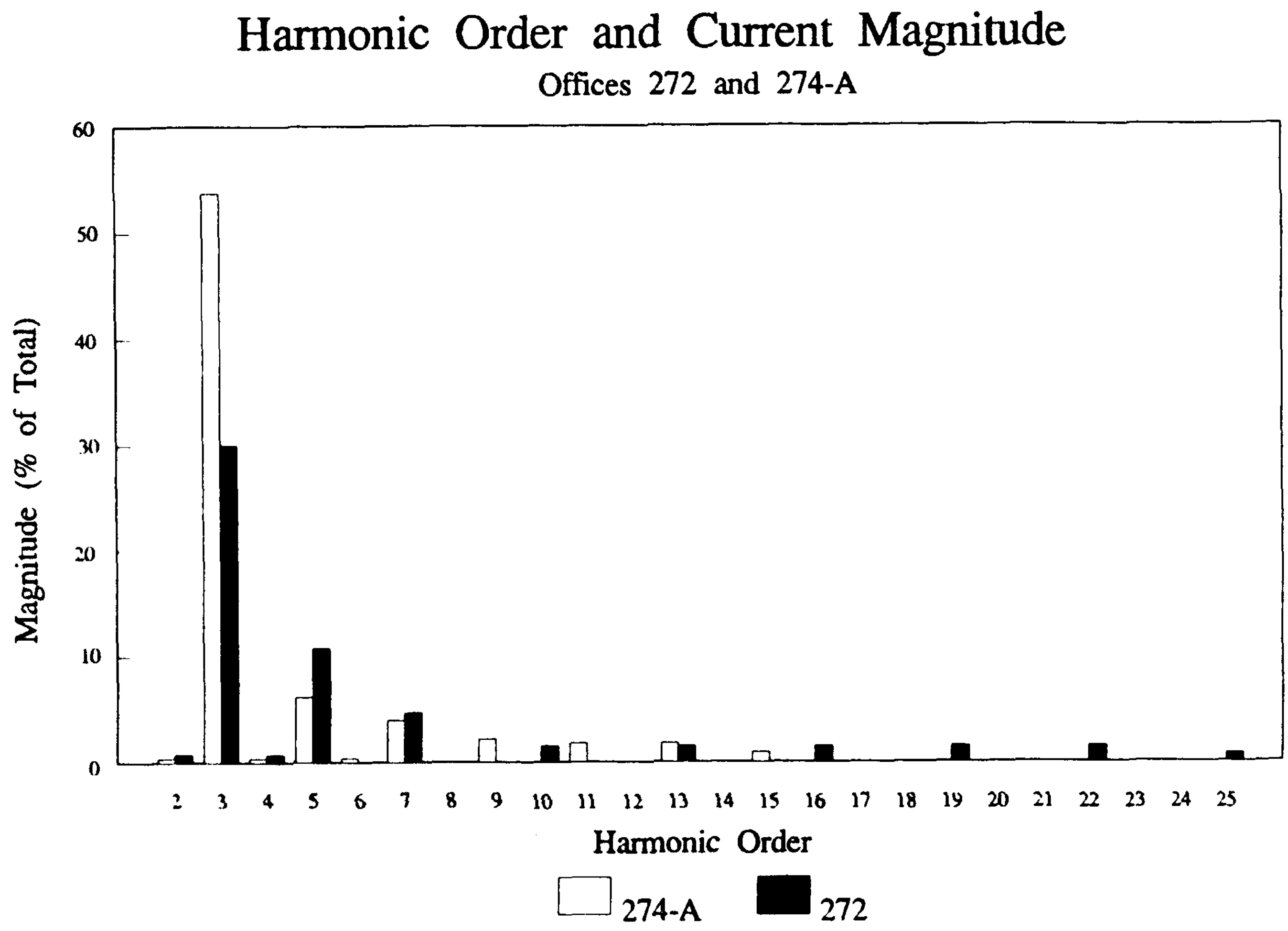


Figure 15. Power factor versus time for two offices.



Measured Parameters for Offices 272 (without CLL) and 274-A (with CLL)

	272	274-A
Volts: Total Harmonic Distortion	1.65%	1.22%
Amps: Total Harmonic Distortion	32.31%	54.19%
Harmonic Power (Watts)	0	24

Figure 16. Harmonic content due to lighting.

The bar graph shows a dramatic increase in the current magnitude of the 3rd order harmonic for room 274-A. The magnitude of the 3rd order harmonic for room 272 is 30.0 percent compared to 53.74 percent for room 274-A. The magnitudes of the other harmonics are within 5 percent of each other. The CLL system in room 274-A is contributing to the large increase in the 3rd order harmonic. The box in Figure 16 lists the significant parameters measured with the Dranetz for both offices. The real difference between the two offices is the harmonic power; room 274-A has 24 watts while room 272 has none. The current associated with the harmonic power is so low for this single office it is negligible. This may not be the case for a building with many Conservolite CLL controllers installed.

Laboratory Testing

A Conservolite CLL controller was tested in the laboratory as a check of the data collected from the field and also as a test of some characteristics that could not be measured in the field. The Conservolite controller was designed to work with a single ballast and two F-40 lamps with 120 volts as opposed to the 277 volts found in the offices where the units were field tested. The test setup consisted of a two-lamp fixture, a new class P ballast, and two new F-40 lamps. The Conservolite controller was mounted outside the fixture to allow easy access for connection and disconnection of the controller for various tests.

The first test of the Conservolite controller was to measure the power factor versus the power over the dimming range of the controller. The real power, current, and voltage were measured using a Valhalla Scientific 2101 Digital Power Analyzer. The power factor was calculated by dividing the real power by the apparent power (current multiplied by voltage). The results of this test are shown by the graph in Figure 17. The graph shows that as the power was reduced, so was the power factor. The power factor drops from 0.869 at 50.4 watts to 0.769 at 32.3 watts.

The Conservolite controller was disconnected from the system and the test was repeated. The power factor was calculated at 0.988 when the real power was measured at 87.8 watts for the test setup without the controller. Adding the controller to the test setup reduced the power factor from 0.988 to 0.869 at full bright and to 0.769 at full dim.

Conservolite claims their controller reduces ballast temperatures, which reduces the cooling load on the building. This reduced cooling load would save energy and money in buildings dominated by cooling loads. A type T thermocouple was taped to the case on the outside of the ballast so that the thermocouple was making contact with the ballast case.

The temperature of the ballast was taken (1) without the Conservolite controller installed, (2) with the controller installed and running the lamps at full bright, and (3) with the controller installed and running the lamps at full dim. The data is shown in Figure 18. The graph shows a significant reduction in ballast temperature for the test setup using the Conservolite controller. The system with controller at full bright shows a 31.5 °F reduction in ballast temperature. When the controller held the lamps at full dim, the ballast temperature was reduced 41.7 °F. For every 18 °F reduction in ballast temperature, the life expectancy of the ballast doubles. If a ballast life at 158 °F is 12 years, reducing the ballast temperature to 140 °F will double the life expectancy of the ballast to 24 years.[3] Reductions in fixture temperatures extends the life of the lamps and increases their light output.

[3] Richard L. Mackey, *Lighting Manual*, Education Foundation, Inc. (National Association of Electrical Distributors, copyright 1982, revised 1985), pp 3-4.

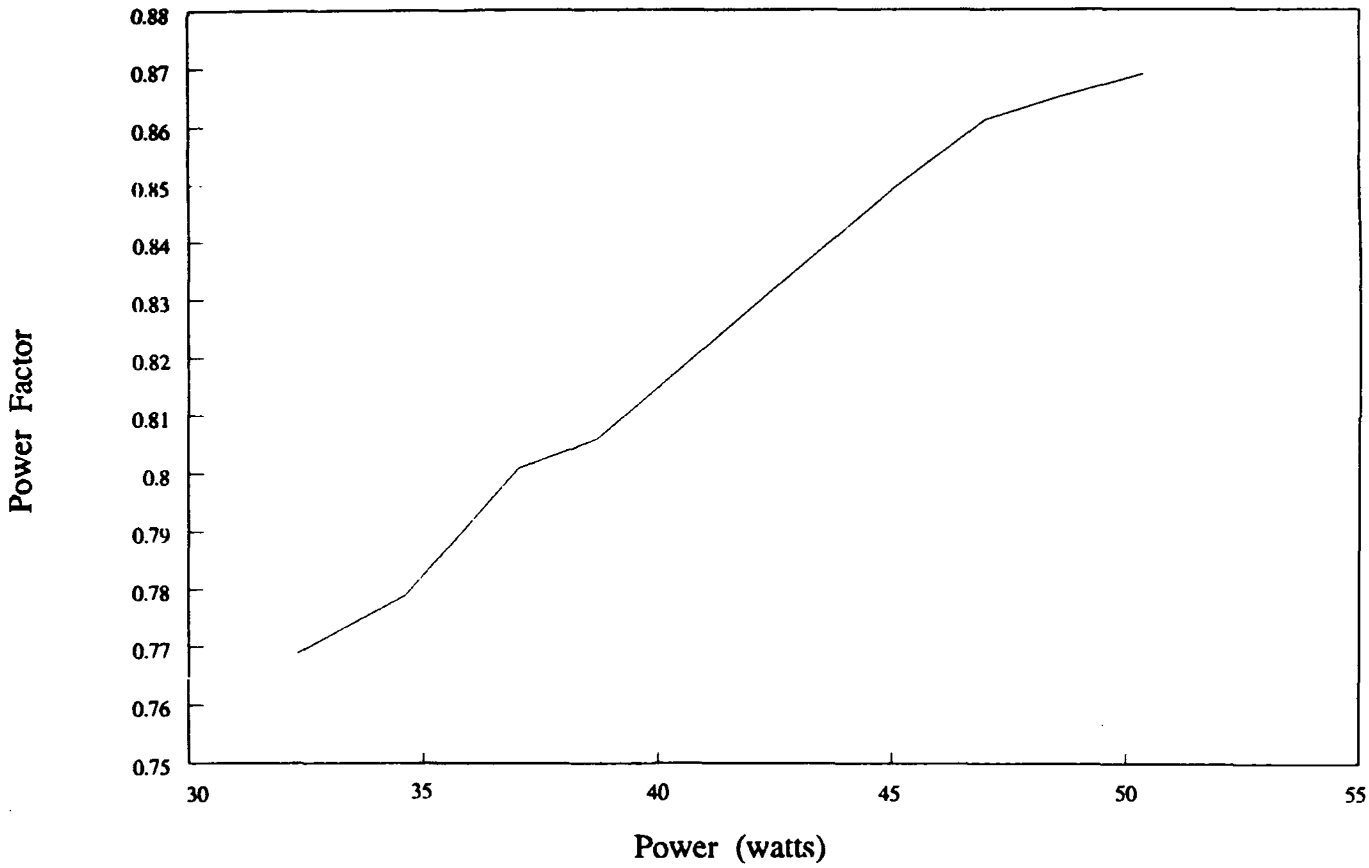


Figure 17. Power factor versus power.

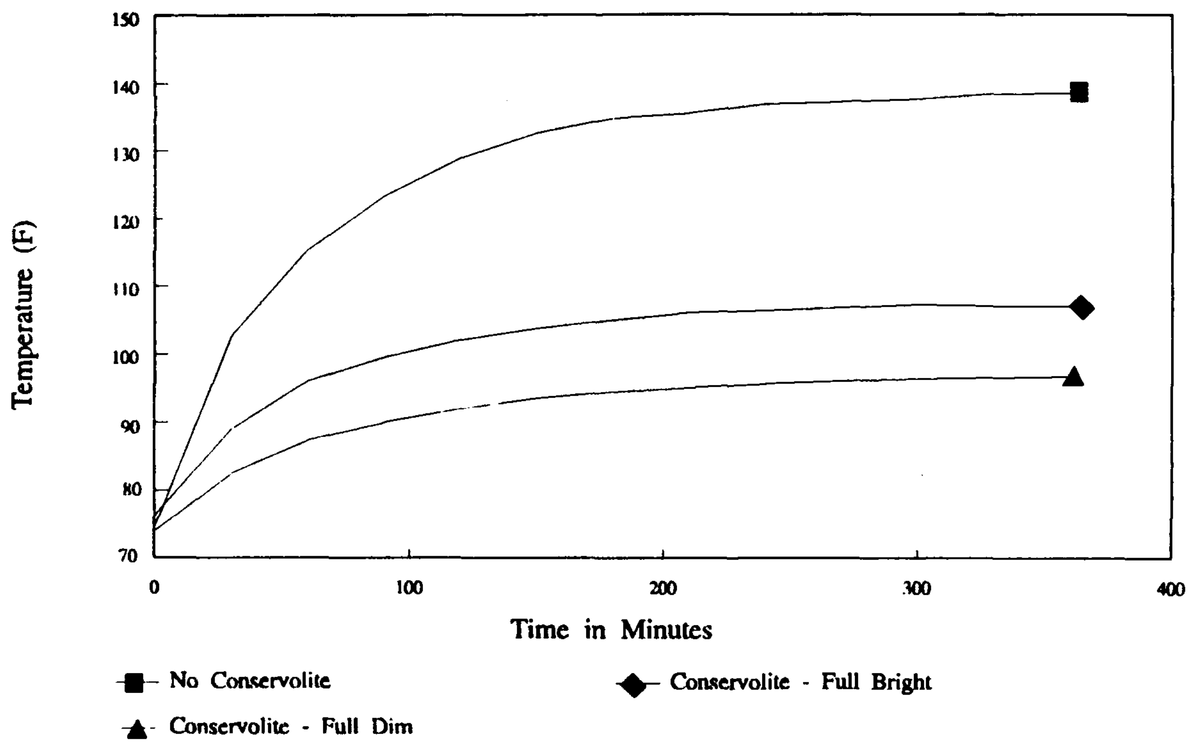


Figure 18. Ballast temperature versus time.

Overall System Performance

The Conservolite constant level lighting system provided energy savings as well as reduced ballast temperatures. The controllers were easily installed and the users felt the CLL systems did not affect their work. The controllers suffered from slight flickering of the lamps during the initial 10 seconds of operation. The controllers were the cause of a lower power factor in the lighting circuit. The system caused an increase in the third order harmonic found in the lighting circuit.

Economic Analysis

Table 2 shows a simple economic analysis for the Conservolite CLL systems in rooms 274 and 274-A. Extended ballast life and possible reduced cooling costs are not included in this analysis. In some instances, these two factors may increase the energy saving and reduce the number of years required for the system to pay back. Based on electrical costs of $15/kW (demand), $.05 per kWh (consumption), and system operation of 2250 hours/yr, cost information was calculated for both offices. The installed cost includes new ballasts and lamps for each fixture. The original energy cost was calculated for the original system using the 34-watt lamps. The calculated energy costs include consumption and demand charges. The increase in energy consumption due to the accumulation of dirt on the luminaries and degradation of the lamps is not included in this analysis.

The CLL system was installed in room 274 at a cost of $259. The original yearly energy cost (consumption charge plus demand charge) was $88.92, which would drop to $53.35 with the CLL system installed. The net yearly savings is $35.57, which results in a payback of 7.3 years. If the system did not require new lamps and ballasts, the payback would drop to just under 4 years.

The CLL system was installed in room 274-A at a cost of $806. The original system energy cost of $263.25 would be reduced to $157.95 with CLL installed. This results in a yearly savings of $105.30 and a payback of 7.7 years. If this system did not require new ballasts and lamps, the payback would be 4.2 years.

Table 2

Economic Analysis Data

Demand charge	$15/kW		
Consumption charge	$0.05/kWh		
Hours of operation per year	2250		
Office 274		Office 274-A	
8F40 controller	$101.00	6 4F40 controllers	$342.00
4 ballasts	$ 72.00	12 ballasts	$216.00
8 F40 lamps	$ 16.00	24 F40 lamps	$ 48.00
Installation	$ 70.00	Installation	$200.00
Installed cost	$259.00	Installed cost	$806.00
Original energy cost	$ 88.92	Original energy cost	$263.25
New energy cost	$ 53.35	New energy cost	$157.95
Yearly savings	$ 35.57	Yearly savings	$105.30
Years to pay back	7.3	Years to pay back	7.7
Years to pay back*	3.8	Years to pay back*	4.2

*The special case applies if the system did not require new lamps and ballasts.

5 CONCLUSIONS AND RECOMMENDATIONS

The Conservolite CLL system provided energy savings and did not affect users, but the low power factor and the increase in harmonics could be detrimental. When there is no power factor penalty and the building does not require new lamps and ballasts, the Conservolite system provides a payback period of about 4 years. The reduction in ballast temperature associated with the Conservolite system should increase ballast life and extend time between lamp changes.

Unfortunately, most of the buildings in the Army are older and in most instances require new ballasts and lamps. Harmonics may also be of interest to the building user who plans to install automatic data processing equipment. For most installations, the power factor would be a concern.

Before CLL systems are installed extensively throughout Army buildings, it is recommended that measurements be taken to determine the effects of the CLL system on a building's power factor and harmonic content. The Butler Veterans' Administration Medical Center, Butler PA, has installed 1530 Conservolite manual and automatic light dimmers in its facility.[4] It is recommended that equipment be temporarily installed to monitor the power factor and harmonic content at the main feed to the facility. The information gathered would provide valuable insight to proper application of this technology and potential energy savings on a large scale.

METRIC CONVERSION TABLE

1 Btuh	=	1,055,870 J
1 ft	=	0.305 m
1 sq ft	=	0.093 m^2
1 kWh	=	3,600,000 J
°C	=	0.55 (°F-32)

[4] Mark Dunbar, "Hospital Saves $6K/Month With Fluorescent Dimmers," *Energy User News*, March 1990, Vol 15, No. 3, p 19; "Lighting Retrofit Cuts Cost In VA Hospital," *FEMP Update*, Spring 1990, Department of Energy, p 12.

APPENDIX A: SURVEY RESPONDENTS

Banner Engineering Corporation
9714 10th Avenue
Minneapolis, MN 55441
(612) 544-3164

Conservolite, Incorporated
McKee and Robb Hill Roads
Oakdale, PA 15071
(412) 787-8800

Controlled Enterprises
P.O. Box 16332
St. Louis, MO 63125
(314) 894-3774

Davis Controls Corporation
5420 Newport Drive
Rolling Meadows, IL 60008
(708) 253-4585

Datalogic, Incorporated
McGregor Park
301 Gregson Drive
Cary, North Carolina 27511
(919) 481-3002

Honeywell, Incorporated
Building Controls Division
621 Route 83
Bensenville, IL 60106
(312) 860-3960

Lutron Electronics Company, Inc.
205 Suter Road
Coopersburg, PA 18036-1299
(215) 282-3800

Multipoint Lighting Control Systems
11812 North Creek Parkway
Suite 101
Bothell, WA 98011-8202

UEC, Incorporated
208-A Industrial Court
Wylie, TX 75098
(214) 442-1900

Valmont Electric
1430 East Fairchild Street
Danville, IL 61832
(217) 446-4600

APPENDIX B: SOLAR METER READINGS

January 15, 1991

Time	Reading (Btuh/sq ft)
0930	50
1030	60
1130	55
1230	40
1330	25
1430	10
1530	10
1630	5
1730	0
1830	0

January 16, 1991

Time	Reading (Btuh/sq ft)
0915	20
1015	20
1115	15
1215	15
1315	15
1415	15
1515	15
1615	10
1715	0
1815	0

January 28, 1991

Time	Reading (Btuh/sq ft)
0900	75
1000	105
1100	125
1200	140
1300	130
1400	120
1500	70
1600	30
1700	10
1800	0

APPENDIX C: BALLAST TEMPERATURE READINGS

January 24, 1991*

Time	Temperature (°F)
1000	74.5
1030	102.6
1100	115.4
1130	123.4
1200	129.0
1230	132.6
1300	134.8
1330	135.5
1400	136.0
1430	136.8
1500	137.2
1530	137.6
1600	137.8
1630	138.4
1700	138.5
1730	138.5
1800	138.5

January 25, 1991**

Time	Temperature (°F)
1200	76.4
1230	89.0
1300	96.0
1330	99.5
1400	102.0
1430	103.8
1500	105.0
1530	106.0
1600	106.4
1630	106.8
1700	107.2
1730	107.0
1800	107.0

* Without Conservolite
** With Conservolite, full bright.

January 28, 1991*

Time	Temperature (°F)
1000	74.0
1030	82.5
1100	87.4
1130	90.0
1200	92.0
1230	93.5
1300	94.4
1330	95.0
1400	95.6
1430	96.0
1500	96.3
1530	96.5
1600	96.7
1630	96.8
1700	96.8
1730	96.8
1800	96.8

*With Conservolite, full dim.

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